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THE STUDY OF VENUS CONTINUES

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16. Abstract

The landing of the Soviet interplanetary station Venera-13 in March, 1982, is described. One of the tasks of the station was to study the composition and structure of cloud layers on Venus. It was established that the cloud layer consists largely of sulfuric acid. Data obtained from other Venera stations are also presented. It is concluded that fundamental similarities can be found in the geological development of the Earth and Venus.

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The Study of Venus Continues

V. L. Barsukov

It has been established that the age of our planet is 4.5-4.8 billion years. Nevertheless, there are on earth no rocks older than 3.8 billion years, or at least none have yet been discovered. Consequently, by studying only terrestrial material we evidently can learn nothing about the first billion years in the life of our planet. However, in recent years we have become convinced that the histories of the formation and early evolution of all planetary bodies of the terrestrial type are fundamentally similar. Because of this, by studying the moon, Mars, and especially Venus, we open, as it were, the first pages in the geological chronicle of the earth. /10*

There is another extremely interesting aspect to planetological investigations. The intensity of development of the biosphere is directly connected with the intensity of the internal (magmatic and tectonic) life of our planet, the character of which was established at the very earliest stages of the earth's formation. Therefore it is extremely important that we understand the laws to which the internal life of the earth and other earth-type planets is subject, that we grasp the particular features of their evolution.

This is why Soviet scientists are studying earth-type planets with such persistence, systematically, one after another, devoting particularly constant attention to Venus, as the planet that is most complex, and at the same time the closest to our earth in structure and developmental history.

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* Numbers in the margin indicate pagination in the foreign text.

Figure. Valeriy Leonidovich Barsukov, corresponding member of the USSR Academy of Sciences, director of the V. I. Vernadskiy Institute of Geochemistry and Analytical Chemistry of the USSR Academy of Sciences, president of the International Association of Geochemistry and Space Chemistry. Specialist in the field of space chemistry and the geochemistry of ore deposits. Author of many works on these questions. Articles published in Priroda: "Atmosphere and rocks of the surface of Venus: facts and predictions" (with V. P. Volkov), 1981, No. 2; "Early history of the planet Earth", 1981, No. 6.

We all know already that on March 1, 1982 the Soviet interplanetary automated station Venera-13 completed a landing on Venus, and on March 5 Venera-14.

This unique space experiment was dedicated to the 60th anniversary of the formation of the USSR. Pennants with a bas-relief of V. I. Lenin were installed on the stations, and state signs depicting the emblem of the USSR on the descent vehicles.

The main goal of the previous launches of Soviet automated stations to Venus was to study its atmosphere comprehensively. In the years that have passed since the launching of Venera-4 in 1967 we have learned much about the atmosphere of that planet. With the launching of the Venera-13 and Venera-14 automated stations - representatives of a new generation of vehicles - the main emphasis in investigations of Venus is beginning to shift to the study of its surface and internal structure. Of course, during the descent of landing vehicles the search for answers to still unresolved or controversial questions concerning the composition and structure of Venus' atmosphere will also continue.

During the descent of Venera-13 and Venera-14 the comprehensive study of the atmosphere of Venus also continued: we wished to obtain new information on its water and microcomponent content, as well as on the content of inert gases and their isotope composition. These data will not only help us to interpret the conditions of the planet's formation and the composition of its primary substance, but also to create a very reliable model of the atmosphere, which can be used to determine the nature of the transformation of surface rocks of Venus upon their interaction with the atmosphere. /11

Another important task of the new automated stations was to study the composition and structure of Venus' cloud layer.

From previous investigations we know that the thick 20-kilometer cloud covering of Venus is located at an altitude of 48-67 km and has a three-tiered structure. Above (up to 85 km) and below it (to 14 km) a sparse cloud haze is observed. It is also known that the clouds consist of spherical liquid droplets and crystals of micron size. But the main question has remained unanswered:

what substance makes up these microdroplets and crystals, what is their chemical composition? Numerous hypotheses have been advanced. Among the "candidates" for the cloud particles have been named drops of water and hydrochloric acid, crystals of chlorides of ammonia, iron, aluminum, and other substances.

Gradually accumulated indirect data have led to the idea that the cloud layer is composed primarily of sulfuric acid; judging according to a number of optical properties, this composition can be identified with concentrated 75-85% sulfuric acid. However, in order to resolve this question conclusively direct determination of the chemical composition of the aerosol in the cloud layer was required.[1]

As the result of preliminary processing of spectra it was established that the aerosol of the cloud layer of Venus indeed consists largely of sulfuric acid with an admixture of chlorides. Sulfur comprises 85%, chlorine 15%.

One important purpose of the launch of the Venera-13 and Venera-14 stations was to carry out fundamentally new experiments on the surface of the planet.

Radar mapping of the surface of Venus by the Pioneer and Venera spacecraft, as is well known, made it possible to reveal four main types of geomorphological provinces: mountain plateaus, hilly elevations, lowlands, and isolated, probably volcanic formations, occupying 7, 61, 27 and 5% of the surface respectively.[2]

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1 The action of the analyzer was based on irradiation of aerosol accumulated on a special filter by radiation sources (^{55}Fe) upon induced injection of the atmosphere and registration of secondary X-ray fluorescent emission.

2 Masursky H. et al. - J. Geophys. Res., 1980, v. 85, No. A13, p. 8232.

According to this classification hilly elevations are the most widespread type of surface on Venus. They are located at an altitude of 0.5-2 km above zero level (R = 6051 km). Numerous ring-shaped formations (primarily of impact origin) and the smoothness of the relief indicate the antiquity of these regions. It can be assumed that the hilly elevations are the ancient crust of Venus.

The second most widespread structural-morphological type of surface (altitude from 0.5 above zero level to 1.5 km below it) are lowlands with relatively smooth relief, within which almost no large impact craters are observed. This indicates the relatively younger age of the lowlands and, by analogy with the moon and Mars, permits one to assume that they consist of rocks of basalt composition.

Less widespread on Venus but, in our opinion, more complex in structure, are mountain plateaus with very broken relief, where numerous linear and ring-shaped structures alternate with high mountain ridges. These huge plateaus (there are only two, Ishtar and Aphrodite), which resemble our continents, rise 2-10 km above the zero level: and while Aphrodite Land changes gradually into the rolling plains surrounding it, Ishtar land is separated from the plains by a sharp, curved shelf of many kilometers.

Circular, very rough mountain structures occasionally encountered among rolling plains are the least widespread on the surface of Venus and resemble young shield volcanoes in their morphology and a number of geophysical features. The main regions /12 of their distribution are the meridian mountain chains Beta-Phoebus and Temis-Alpha.

The landing points of the Venera-13 and Venera-14 stations were selected so that the two most widespread structural-morphological types of the surface of Venus - the ancient rolling plain and the lowland - fell into the field of vision.

The Venera-13 station landed on an elevation (altitude 1.5-2.0 km above the zero level of the surface) at a point with coordinates $\varphi = -7°30'$ and $\lambda = 303°11'$, and Venera-14 landed in the lowland (altitude 0.5 km) at the point with coordinates $\varphi = -13°15'$ and $\lambda = 310°09'$.

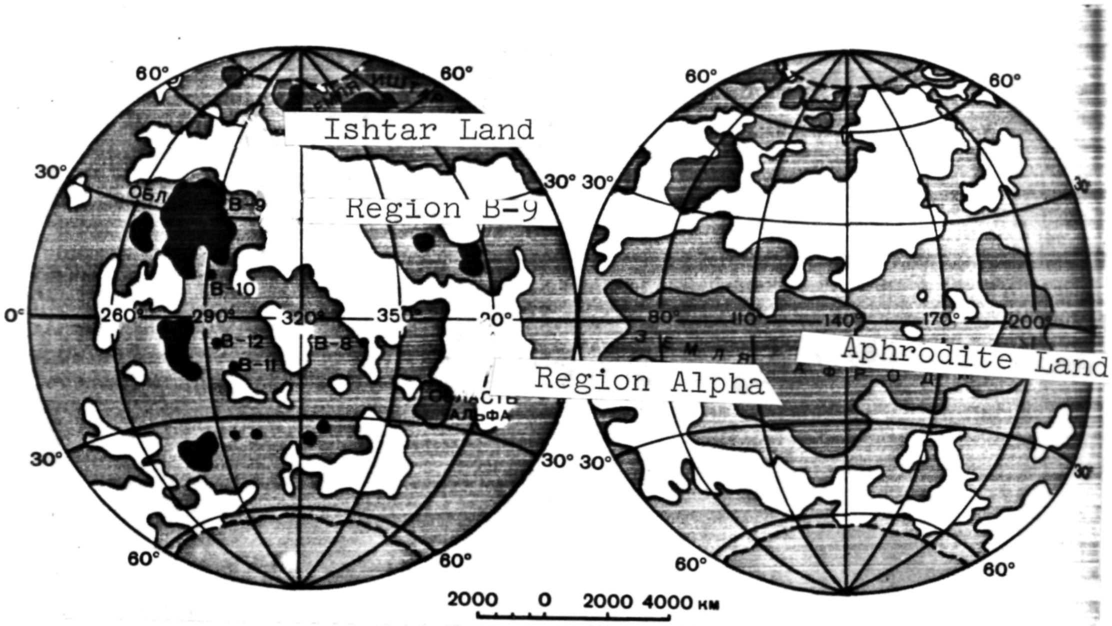

Figure. Schematic geological map of Venus constructed on the basis of radiolocation data of the Pioneer and Venera spacecraft. Dots indicate the landing sites of the automated interplanetary stations Venera-8, -9, -10, -11 and -12.

Hilly elevations

Gently sloping lowlands

Mountain plateaus

Mountain ridges

Volcanic structures

Unphotographed territory

Table 1

Chemical composition of rocks of Venus and earth rocks similar to them, %

	Venera-13	Shoshonite	Teschenite	Venera-14	Toleite basalt
SiO_2	45.1	53.56	44.34	48.7	50.6
TiO_2	1.59	0.82	1.24	1.25	1.2
Al_2O_3	15.8	17.88	15.07	17.9	16.3
FeO	9.3	7.10	9.56	8.8	8.8
MnO	0.2	0.07	0.20	0.16	0.2
MgO	11.4	3.62	7.37	8.1	8.5
CaO	7.1	6.45	12.03	10.3	12.0
Na_2O*	2.0	3.41	2.35	2.4	2.4
K_2O	4.0	3.76	3.80	0.2	0.1

Content of Na_2O calculated according to the difference between $K_2O/(K_2O + Na_2O)$ and $FeO/(FeO + MgO)$.

From panoramas of the surrounding terrain taken from the stations /13 Venera-13 and Venera-14 it can be seen that the morphology of the surface and the aspect of rocks at the sites of their landing differ considerably. The Venera-13 station descended in a stony desert with low outcrops of hard bedrock, in the depressions between which the darkest surface of fine-grained soil is visible. The soil is variable: in addition to fine-grained, it includes angular fragments up to 5 cm in size. In the left and right corners of the panoramas at the horizon line (approximate distance from the station 100-200 m) low (4-8 m) steep hills can be seen. Through the haze vague contours of more remote elevations are visible. In the left section of both panoramas, which were taken from the Venus-13 station, in large blocks of rock and in bedrock outcrops weathering caverns (possibly flattened crystals) oriented in one direction, i.e.

signs of the trachitoid nature of magmatic rocks, are clearly visible. The general aspect of the bedrock outcrops testifies to their high degree of chemical weathering.

The data obtained on the chemical composition of the rocks (see Table 1) indicate that in the area of the Venera-13 station bedrock is represented by potassic high-magnesium alkaline basalt. In the same table the results from chemical analysis of toleite basalts that are similar in composition, as well as shoshonites and teschenites (alkaline rocks of the traprock formation of Siberia) are presented for comparison. The large potassium and magnesium contents of the rocks encountered on Venus, as well as the low concentration of silica, speak of the great depth of generation of the original melts and their low degree of differentiation. On earth the tendency for magmatic rocks to be enriched with potassium appeared only 2.0-2.6 billion years ago. We do not know the age of the rocks from Venus that were analyzed, but, considering their deep chemical weathering, the possibility is not excluded that here as well we are dealing with very old formations.

As is known, the previously launched Venera-8 and Venera-10 stations were landed on rolling plains, but several thousand kilometers east and northwest of the site of the Venus-13 station's future landing. Indeed, the aspect of the surface in the panoramas obtained from the Venera-10 and Venera-13 stations are practically identical, which indicates the typical nature of the relief observed in the panoramas and of the forms of rocks for the given structural-morphological type.

At the landing sites of Venera-10 and Venera-8 the full chemical composition of the rocks was not determined, and we have access only to data on the potassium, uranium and thorium contents in the rocks. On the basis of the content of these elements and their ratio, the rocks in the region of the Venera-8 station's landing are classified as shoshonites (possibly with a certain deviation toward syneite rocks), and in the area of the Venera-10 station's landing as basaltoids of traprock formation.

Table 2
Mineral norm of rocks from Venus and earth rocks similar to them, % by weight

	Venera-13	Shoshonite	Teschenite	Venera-14	Toleite basalt
Hypersthene	--	4.7	-	18.2	14.2
Olivine	26.6	9.4	13.7	9.1	8.1
Diopside	10.2	8.3	32.9	9.9	21.2
Anorthite	24.2	23.1	20.1	38.5	33.6
Albite	3.0	29.9	-	20.7	20.3
Orthocloase	25.0	23.0	-	1.2	0.3
Nepheline	8.0	-	11.2	-	-
Leucite	-	-	18.4	-	-
Ilmenite	3.0	1.6	2.5	2.3	2.3
Monticellite	-	-	1.3	-	-

All of this makes it possible to conclude that the ancient rolling plains of Venus consist mainly of lava tufa of alkaline basaltoids with a clearly manifested tendency to be enriched with potassium. This is also indicated by conversion of the chemical /14 analysis of the rocks at the landing site of the Venera-13 station to the mineral norm[3], which is done without consideration of secondary changes in the rocks and the volatile components contents in them (see Table 2).

In the panoramas from the Venera-14 station a relatively level sector of stony plain can be seen - a uniform outcrop of rock extending to the horizon. The rocks here lie in the form of horizontally-oriented layers. In the relief they form numerous steps from 1 to 10 cm in height. The surface of the layers is level, clean, with winding cracks resembling shrinkage cracks. There are no noticeable accumulations of dark soil within the range of vision, unlike the landing site of Venera-13. Nor are elevations visible at a distance from the vehicle. The line of the horizon is quite level, with no noticeable curves.

The stratification of the rocks at the landing site of Venera-14 is very clearly marked. The number of layers observed within the range of vision is quite high. The great horizontal extension of the layers and their uniform subhorizontal position compel us to think that here we see sedimentation-type stratification, in which the minute particles that served as material for the stratified rocks were evidently deposited in a very calm, non-turbulent medium.

The external aspect of the rocks and the planet's surface at the landing site of the Venera-14 station is typical for territories covered with deposits of pyroclastic (primarily ashy) material discharged during the explosive eruptions of volcanoes. We know that on earth similar deposits cover many thousands of square kilometers, and even now, with limited volcanic manifestations, the discharge of fine pyroclastic material reaches 3 billion tons per year.[4]

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[3] The norm is the mineral composition of magmatic rocks calculated from chemical analyses, based on a conditional standard and expressed in percentages of weight of the so-called standard minerals.

[4] Markhinin Ye. K. Tsep' Plutona [The chain of Pluto]. M., 1973.

The explosive volcanic origin of the rocks observed in the panoramas of Venera-14 is also indicated by the presence on the surface of lapilli and volcanic bombs that are typical in their external aspect. For example, in the right section of the upper panorama, not far from the station's landing ring, a stone block can be seen that in texture (well defined dark layers, lenticular accumulations of volcanic glass) and morphology (lengthwise furrows, smoothed forms on the "windward" side, etc.) is analogous to the so-called spindle-shaped volcanic bombs known on earth. /16

In their composition the rocks in the landing area of the Venera-14 station correspond to oceanic toleite basalts of the Mesozoic and Cenozoic eras, which are widespread on earth. It is curious that eruptions of an explosive nature are not characteristic of these basalts: the discharge of pyroclasts with formation of volcanic tufa on earth takes place during eruptions of more acidic (rich in SiO_2) and viscous magmas with an andesite-dacite composition. The presence on Venus of similar formations of more basic (poor in SiO_2) composition indicates the high gas saturation of those basaltic melts, which produced the mantle of Venus. At the same time, the lack of similarity between the basaltoids of Venus and rocks of andesite composition permits /17 one to propose that the mantle and basaltic melts of Venus are poor in water. All of this as a whole seems to testify to the richness of the melts in carbonic acid and their water impoverishment; with this the high carbonic acid content in the early basaltic melts that welled out on the ancient rolling plains, as compared with those that are younger, may have caused their enrichment with alkaline elements, above all potassium.

Thus we already have an idea of the main types of magmatic rocks that have been developed within three structural-morphological

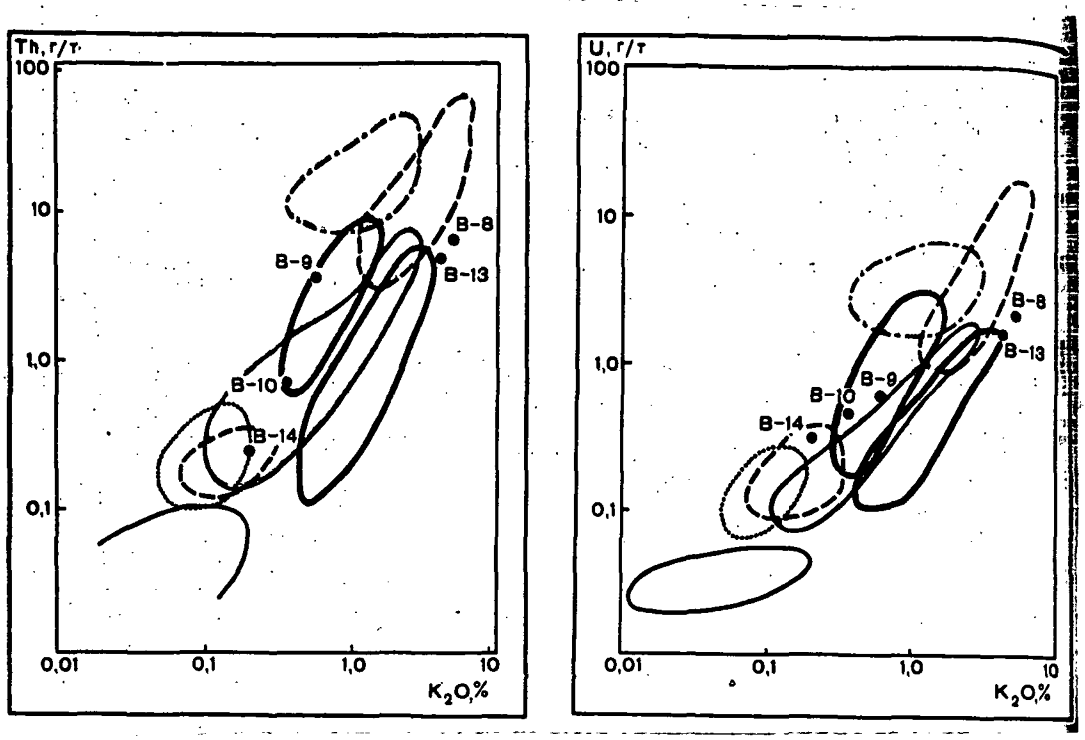


Figure. Ratio of Th and K_2O (left), U and K_2O (right) in the most widespread magmatic rocks of earth and in the rocks of Venus analyzed.

Comatites

Garnet peridotites

Oceanic toleites

Toleite rocks of archipelagos

Limestone-alkaline rocks of archipelagos

Continental traps and toleite rocks of the Afar Rift

Kimberlites and alkaline picrites

Alkaline rocks of oceanic islands and continental rifts

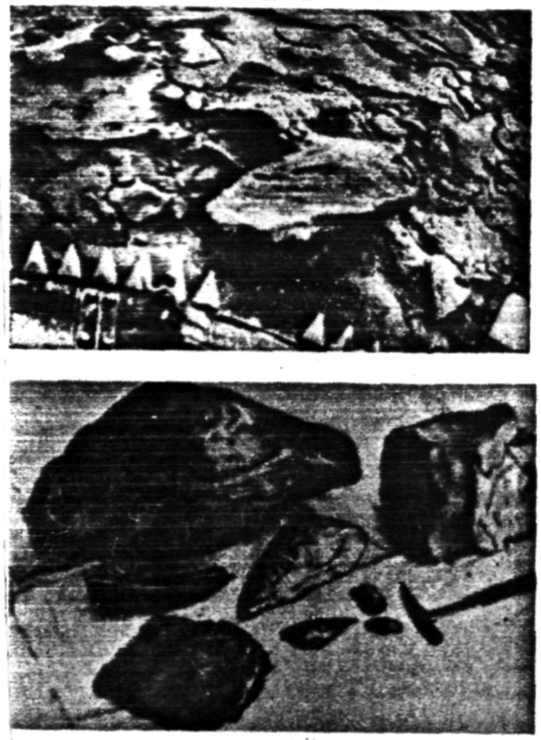
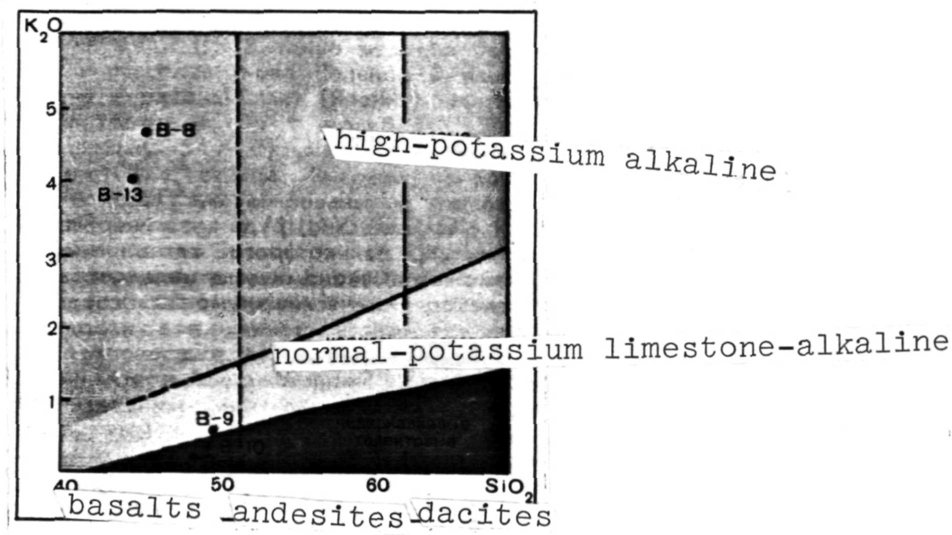


Figure. Volcanic bomb on the surface of Venus (top) and spindle-shaped volcanic bomb of earth (bottom).



Fields of toleite, limestone-alkaline and alkaline rocks of earth distinguished according to the ratio of silicon oxide and potassium oxide (%) in those rocks. Dots indicate the ratio of these oxides in the rocks of Venus analyzed.

types of the surface of Venus, and which correspond to the three tectonic and magmatic stages of its evolution, although we do not know what period of time was covered by each stage. These are ancient rolling plains consisting of "normal" and potassic alkaline basalts (the latter apparently having the predominant development); lowlands covered with volcanic tufa of toleite basalts; young shield volcanoes that produce lava similar to limestone-alkaline basalts. As we see, all three types of the surface of Venus, although formed at different times, are made up of the basic magmatic rocks of the basaltoid order. Differences in the composition of the rocks making up the various structural-morphological types reflect not only the different times of formation of the rocks, but also the varying conditions of their genesis.

With this, of course, the question of whether the data obtained are representative of all of the vast territory of the plains and lowlands of Venus still remains open. This is especially true as we still know nothing about the composition of the rocks making up the analogs to our continents (Ishtar Land and Aphrodite Land), where much greater variety probably awaits us.

On the whole, one can say that fundamental analogies can definitely be traced in the history of the geological development of the earth and Venus, although the extent and composition of the magmatic products covering these planets differ. This is probably connected with the differing temperatures on the planets' surfaces and the removal of water from the geochemical cycle of Venus at the earliest stages of its existence.[5]

[5] This occurred due to the decomposition of water in reactions of oxidation of iron, sulfur, carbon and other elements, and the dissipation of hydrogen into outer space.